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# ABRASIVE MACHINING OF MAJOR COMPONENTS

John Rodd



May 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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The term "abrasive machining" has been expressed in many ways. It is generally used to denote stock removal operations that are more economically performed by abrasive grinding methods than the more conventional means of turning or milling. The two largest fields for abrasive machining are the production of flat surfaces and form grinding from the solid. This report is concerned with the latter; grinding various complex external shapes from the solid forging, bar stock or hollow cylindrical items.


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TABLE OF CONTENTS

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BENET WEAPONS LABORATORY, LCWSL
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DRDAR-LCB-SE

Project No. 6747408

Project Title: MM&T Abrasive Machining of Major Components

Statement of the Problem: To develop equipment, techniques, and processes which would allow major ordnance items to be successfully produced by crush form abrasive grinding. This will include development of engineering specifications, and a cost analysis.

Background and Introduction: A previous project 6717030 "Abrasive Machining of Minor Items for Cannon Manufacture" proved that this technique was a reliable manufacturing process for the production of minor ordnance components. As a result, it was determined that this process could be applied to machining gun tubes at a considerable cost savings.

Abrasive machining is perhaps the least understood metalworking development to occur in the past decade. It pertains to stock removal operations which are more economically accomplished by abrasive grinding methods than turning. This program is concerned with grinding various complex external shapes in the tube forging, or hollow cylinder.

Abrasive machining has been used in recent years when metal removal rate, surface finish and accuracy are the main considerations. It includes all operations where cost is a major factor in determining whether to grind or to machine with carbide or high speed steel cutters. To compete with other processes, machines used for abrasive machining must employ much higher horsepower wheel drives and must be dynamically stiffer to utilize this power. In addition, to realize the most benefit from high speed grinding and abrasive machining, special high strength grinding wheels, machines which have sufficient dynamic

This project was accomplished as part of the US Army Manufacturing Technology program. The primary objective of this program is to develop, on a timely bases, manufacturing processes, techniques and equipment for use in production of Army materiel.

rigidity, properly selected grinding fluids, and a truing medium that offers efficient wheel dressing, should be employed.

Abrasive machining of major items such as the breech thread diameters as specified on the 105mm M68 cannon tube was completely out of the question two years ago. Capital equipment capable of removing the volume of metal necessary to produce a finished 105mm M68 thread blank diameter was not available. Adequate horsepower drive systems along with solutions to numerous engineering problems such as developing a variable speed drive while maintaining constant torque were only a few factors which had to be resolved before testing could be achieved. Metal removal rates of the experimental machine must exceed those of the conventional cutting techniques. Operating cost, capital investment, flexibility, product reliability, surface finish and labor requirements must benefit from the use of abrasive machining. It was concluded that a comprehensive abrasive machining program would produce exceptional results and reflect definite gains in advanced technology and long term financial benefits.

The purpose of this report is to inform managerial, engineering and technical personnel responsible for the manufacture of cannon about the advantages of abrasive machining. The success of this experimental application has led to the development of engineering specifications for the design of highly specialized capital equipment and support hardware. The work performed encompassed many areas of investigation, all of which are covered in this report. Specifically, these areas include equipment design and specifications, techniques, piece rate, component handling time, production, tooling, gaging, speeds and feeds, coolant systems, drive systems and cost analysis.

Approach to the Problem: As was previously men ioned, an "Abrasive Machining of Minor Items for Cannon Manufactu ' project has already been completed. For this program certain guide lines established from the prior project were followed. It became apparent from the previous work that if abrasive machining was to find its way into industry as a competitive, practical method of manufacture, a system integrating all the necessary factors of rigidity, high horsepower, high velocity, long life wheels, new wheel cleaning techniques, coolants, and many other technological advancements would be necessary.

This report will show the cost reduction and improved component finish that can be achieved by completing a specific area of the cannon in one plunge of the grinding wheel. This approach reduces component handling, set up and machining time. In order to develop proper

operating parameters, it was decided that two particular gun tubes, the 105mm M2A2 and the 105mm M68, would present the most practical approach. This would represent a cross section of most major components, to include breech blocks and breech rings.

A product survey was performed which determined that the most economic advantage would result from a system designed specifically to handle a variety of cannon tubes. Several scrap 105mm M68 and 105mm M2A2 gun tubes were obtained for the actual tests (Appendix A, Component & Tooling Test). The purpose of these tests was to develop the engineering data necessary to design major capital equipment capable of producing breech thread blank diameters on gun tubes varying from 90 to 260 inches in length and weighing from 1000 to 6000 pounds each.

Equipment possessing suitable horse power and constant torque deemed necessary for abrasive machining was not available either in industry or government; consequently, all tests were contracted out to be run on converted machinery with insufficient drive systems. Although low horsepower equipment was used, it was felt that sufficient engineering data could be obtained in order to establish design criteria for development of proper equipment. It was believed that a corollary existed between volume of metal removal and grinding forces developed. It was known that an optimum grinding ratio between wheel surface speed and work surface speed is approximately 60 to 1. Technical data established by Bendix Automation and Measurement Division has confirmed this. Bendix data shows that while increasing the wheel speed to 18,000 surface feed per minute and maintaining the 60 to 1 ratio, the overall metal removal rate and grinding forces increase proportionately. It must be pointed out, however, that, if the grinding forces are held constant, the metal removal rate is increased by about 150 percent. But, if the metal removal rate is held constant, the grinding forces will be reduced by approximately 80 percent. These results can be exceeded by decreasing the wheel speed to workpiece speed ratio.

If we design for wheel speed of 6000 surface feet per minute and workpiece rotation speed of 100 surface feet per minute, the ratio is 60 to 1. If the wheel speed is increased to 18,000 surface feet per minute and the workpiece speed upped to 600 surface feet per minute, the ratio is now 30 to 1. An observation that can be made is that the use of higher workpiece speeds is one key to the success of abrasive machining. Higher workpiece speeds will tend to increase production many fold. The reason for the dramatic change is not fully understood but it is felt that cutting grain efficiency is directly benefited.

Testing at higher feeds and speeds on modified equipment resulted in excessive vibration. This put a ceiling on test data. However, sufficient data was gathered to enable an adequate machine specification

to be prepared. Further, having established the above relationship, it was concluded that it was neither practical nor necessary to continue testing on inefficient modified grinding equipment. Metal removal at high surface speeds requires a system designed specifically for that purpose.

## The Machine

Tests conducted by the Bendix Company and the Machine Processes Activity have shown that without machine stiffness and rigidity, the high wheel and workpiece speeds required for economical abrasive machining will result in excessive vibration and workpiece chatter. This will result in wheel failure and out-of-tolerance workpieces. For maximum rigidity, it is felt that the machine must be made of a heavy box type casting of close grained cast iron or semi-steel reinforced with heavy cross sections to provide maximum support to the critical stress areas. To eliminate the necessity for any special foundation, the base must be self supporting, covering sufficient area so that the platen, which carries the work head, work and tailstock will have a suitable cradle area.

The wheelhead and work spindle system must be of the large roller bearing type of the dead shaft design, with a rotating housing rigidly supported at both ends. This design minimizes or entirely eliminates vibration that is present with the cantilever type spindles. Abrasive machining requires considerably more power than conventional type machining because of greater machining area and higher rate of stock removal. This applies to all factors such as horsepower, torque, refrigeration, coolant, wheel cleaning, etc. The wheel power drive requirement increases almost linearly with the wheel surface speed. Assuming 30 horsepower is required for operating at 7000 surface feet per minute, 75 horsepower will be necessary for 18,000 surface feet per minute using a 6 inch wide wheel. The machinery discussed in this report requires 150 horsepower and a 42 inch diameter by 12 inch wide wheel. The work head drive system will require a minimum of 25 horsepower in order to adequately drive the gun tube against the 12 inch wide work wheel.

## Grinding Wheels

One of the major technological advances which was required by abrasive machining was the development of effective safe wheels. The wheels available today can operate at speeds in excess of 20,000 surface feet per minute. Such wheels must be formulated with special bonding agents capable of withstanding the high stresses generated at elevated rotational speeds. They must be carefully speed tested prior to use. The abrasive wheel test code, now incorporated in OSHA* standards, requires wheel testing at speeds at least 50 percent higher than the designed operating speed. It becomes the responsibility of the user to totally familiarize

*Occupational Safety and Health Standards

the operating personnel with recommended techniques for wheel handling, mounting, dressing and storage. One particular safety feature has been the prevention of carelessly mounting a low speed wheel on a high speed machine. High speed machines are built with special wheel mounting hubs. Only high speed wheels have these special hub diameters.

## Dressing the Wheel and Crusher Materials

Generally there are three accepted ways to produce a specific contour on a grinding wheel for form grinding. One employs a single point diamond, controlled by a template device. This method is slow and dulls the wheel as a diamond will cut off all the sharp grit as it traverses across the wheel. Another uses diamond roll dressing or CDP (Cemented Diamond Particles). In this method, a small form roll, covered with diamond particles of the same cross section as the work piece, is driven against the rotation of the wheel, cutting the inverse form onto the grinding wheel. This method of dressing is fast, but also dulls the wheel, making it necessary to dress the wheel more often. The latest and most successful method is the crush dressing process. A hardened roll having the same cross section as the work piece is forced to run with the wheel under pressure at a slow R.P.M. This imparts the inverse form of the roll onto the wheel. Rolls are about 1/5 the diameter of the grinding wheel. They can be made of high speed steel, tungsten carbide, or boron-carbide, depending upon the form and the roll life desired.

There are several advantages of crush dressing over the other conventional methods. In the crushing process, the roll does not do any cutting, but breaks down the bond of the wheel, allowing the loose grit and bond to be washed away. This leaves the sharp edges and points of the remaining grit exposed to do the grinding. The wheels are sharper and consequently cut faster, cooler, and longer between dressings. Crushing leaves a more open structure, called voids, to carry lubricant to the cutting zone. This reduces dulling of the wheel and surface heat in the work piece. Either tungsten carbide or boron carbide is recommended for this project; both are more economical than diamond rolls. The cost ratio is approximately 3:1. Work piece dimensions and tolerances can be changed by regrinding the crush roll. It is usually very difficult and not practical to make changes on a diamond roll.

A grinding wheel may become loaded with particles of the material being ground. This can lead to excessive heat generation, poor finish and inaccurate parts. Wheels are dressed to expose not only sharp abrasive grains, but to eliminate loading. When loading does occur (in the absence of grain dulling), it is advantageous to be able to eliminate it by some means other than dressing. Industry has developed the jet wheel cl-aner for this purpose. It oscillates a high pressure (10,000 psi) jet of grinding fluid across the wheel face during grinding.

Material particles are blasted loose before they become embedded in the wheel. The grinding fluid is forced into the interstices of the wheel. Part of the fluid is forced out in the area of grinding contact. This process has increased pieces per dressing, production rate and wheel life, and has made it possible to grind forms that could not otherwise be produced.

## Coolant System

The coolant system is a critical factor in the abrasive machining process. This includes the cutting fluid, coolant pumps, filtering unit and refrigeration unit. In some cases, special coolant nozzles are required. The most satisfactory coolants for crush grinding are oils. Several of their desirable properties are:

1. Relatively low viscosity at ambient temperature.
2. Good lubricity,
3. Good heat transfer capacity.
4. Long life.

Adequate and rapid provisions for heat removal are of prime importance. Abrasive machining at elevated speeds produces a tremendous amount of heat and, unless the heat is rapidly dissipated, it can have detrimental effects on both the product being machined and the grinding wheel. An overheated workpiece will expand, causing shoulder burning, surface cracking and out of tolerance parts. In tests conducted by Bendix Co., it was found that an overheated wheel may be subjected to excessive wear and frequent breakdowns. A coolant flow rate of 4 gallons per minute per horsepower on the wheel spindle is adequate for most jobs when the coolant is properly directed to the cutting zone. Nearly all the grinding horsepower is converted into heat in the grinding process which is concentrated in the cutting zone. This obviously causes high temperature at the interface of the wheel and the work. If the workpiece is slowly rotated, the heat is rapidly conducted into the work and is not easily removed by the grinding fluid. However, if higher work speeds are used, along with reasonable depth of cut per revolution of the work, heat penetration may be reduced by the wheel removing part of the heated work on each subsequent revolution.

Coolants are perhaps the most abused segment of any precision grinding operation. In many grinding operations, the coolants lack cleanliness. The coolant must be clean necessitating an efficient filtration system which will remove all particles larger than 25 microns in size. If the coolant is not kept clean, excessive crush roll wear, wheel loading and excessive heat build-up can result.

It is important to maintain the coolant at a chilled temperature to dissipate heat during the grinding operation. This will maintain uniform dimensional performance of the grinding machine and will result in uniform production of parts. Where the heat of grinding is of a magnitude that normal heat dissipation during the filtering cycle is not adequate, refrigeration is mandatory. Coolant temperature is generally maintained at approximately 62°F.

Careful consideration must be given to coolant application. An abrasive wheel 12 inches wide and 42 inches in diameter running above 7000 surface feet per minute generates an area of protective air between the wheel and the rotating workpiece. Coolant penetration to the workpiece and wheel is strongly resisted. The result is dry grinding which cannot be tolerated. To prevent this, deflectors and specially designed coolant nozzles must be employed. Coolant pumps capable of supplying 150 gallons per minute at 150 pounds per square inch pressure must be included in the system.

The coolant system must be equipped with an adequate air filtration device such as an electrostatic precipitator capable of removing all the oil saturated mist. The system must process a minimum of 2400 cubic feet of air per minute. The mixture of air, coolant and an assortment of grinding debris is drawn through filters and ionized by a high voltage charge which separates the particles from the air. Clean air is returned to atmosphere, grinding debris is moved to a collector and the coolant oil is returned to the reservoir. During testing on the converted equipment, a Smog Hog system was used which produced satisfactory results.

A super jet wheel cleaner, described previously, is recommended on all abrasive machining operations to prevent wheel loading. The use of a jet wheel cleaner necessitates the use of a mist collector coolant filter to prevent fogging in the work area.

## Safety

Bendix Company and Machine Processes Activity personnel determined that considerable attention must be paid to the safety aspects of abrasive machining, particularly where high wheel speeds are involved. A great deal of extra design and testing effort was directed to this phase of the total system. High speed abrasive machining is no more hazardous than that of standard grinding systems if proper precautions are observed. Designs should include multiple interlocks, which make it impossible for machine motions to occur in any but the proper sequence. One particular example is the design of the previously mentioned high speed wheel.

In the event of wheel failure, special precautions should be taken to ensure that no fragments will fly from the wheel or work area. Properly designed guards to contain even the most severe failure are mandatory. These guards must be capable of absorbing tremendous impact loads and to retain fragmentation ricocheting. Bendix recommends that all guards be lined with a shock absorbing material that will contain a broken wheel and also prevent serious damage to the machine and work being processed. It is extremely important that the machine operators and set-up personnel are thoroughly trained to understand each portion of the system and how it operates or relates to other parts of the machine. Particular emphasis should be placed on proper handling of the massive abrasive wheels, including crack detection and inspection, mounting procedures, balancing, etc.

It should be clear from the material presented that high speed abrasive machining offers tremendous potential for reducing manufacturing costs. The extent to which costs are reduced will depend not only on the degree to which the system is optimized, but also on the nature of the parts selected for high speed abrasive machining.

With all preliminary experimental tests completed, it was felt that sufficient data existed to design capital equipment and peripheral support hardware to complete this project.

## Solution to the Problem:

During the past two years, over thirty individual tests have been completed using modified converted factory equipment. The success of testing led to the development of engineering specifications for the design and construction of highly specialized equipment and all support hardware. The work performed encompassed engineering design, production, tooling, coolants, speeds and feeds, and cost analysis.

Bendix Corporation, Automation and Measurement Division perfected experimental equipment and techniques which showed abrasive machining to be a realistic production tool. Metal removal rates of the experimental machine exceeded those of conventional cutting tools. Tool life, operating costs, capital investment, flexibility, and reduced labor requirements were benefited by the use of abrasive machining. A proposed method for producing all the dimensions required for the manufacture of breech thread blank diameters of various gun tubes was completed. The experimental high speed abrasive machining process, as applied to this operation, was done in three passes of the machine. The reason for not completing the cut in one pass of the grinder is that sufficient horsepower and torque for both the wheel head drive system and the work head drive system were not available on the converted equipment. However, after all preliminary experiments had proven the technique practical, consultation and extensive engineering were centered around total design parameters for development of specifications for construction of major capital equipment to produce finished breech thread blank diameters in a variety of gun or cannon tubes.

Title: Abrasive Machining of Major Components

Technical areas of this report will contain a summary of all data collected and results achieved for the various phases.

Appendix A contains technical information on components, tooling, process data, cost analysis, cost comparison and projected cost savings.

Appendix B contains Engineering Specification (RS-6-76) depicting all the equipment required for construction of machinery and support systems.

Conclusions:

1. Abrasive machining is a highly competitive metal removing process with fast stock removal ability.

2. Material waste is reduced because parts can be cast or forged to closer size.

3. Abrasives are not affected by variations of surface quality whereas cutting tools need extra allowances to cut through hard scale or work hardened surface layers.

4. Interrupted cuts do not affect abrasive machining.

5. Hardened steels, from $R_c$ 60 up are ground as a matter of course.

6. Tooling costs and general maintenance are commensurately lower when abrasive machining is applied. It is reasonable and realistic to anticipate savings in excess of 85% when this technique and equipment are adopted to production of cannon and cannon components.

7. Parts having multiple diameters, chamfers, radii and shoulders can be ground in one plunge of a formed wheel, eliminating several separate operations and machine tools, reducing parts handling and floor space.

8. Parts that normally require rough, semifinish and finish machining can be completed on one set-up, generally from the rough casting or forging to the finished product.

9. High speed abrasive machining offers tremendous potentials for reducing manufacturing costs. The extent to which overall costs are reduced will largely depend on the degree of general application.

As can be seen from Figures 2 and 5, the specifications for the breech thread blank diameter contain requirements for grooves, radii, different

diameters, shoulders and chamfers. Parts or components of systems requiring this type accuracy and surface finish are common to the field of cannon manufacture and usually can be handled with one plunge of the formed wheel. This replaces multiple turning, grooving and usually semifinish and finish machining. Since the full form is established by the crush roll, the relationship between various surfaces, shoulders and chamfers remains constant. Therefore, repeatability of dimensional accuracy is exceptionally good. Usually, inspection for conformance of part configuration is reduced to only checking of one critical dimension. If this dimension is within tolerance, all other dimensions will also be within tolerance and acceptable, reducing the inspection time considerably.

The abrasive machine proposed as a result of this effort will have the great advantage of flexibility for the production of a wide variety of different shapes and diameters. The crush roll and grinding wheel can be quickly and simply assembled and disassembled. The wheel and crusher roll can be conveniently stored in a tool crib and recalled when that specific part or shape is again required, constituting a complete tooling package easily inventoried.

## APPENDIX A

## ENGINEERING

## Appendix A

### Component and Tooling (Summary)

Several 105mm M68 (Figs 1, 2 and 3) and 105mm How M2A2 (Figs 4, 5, and 6) scrap tubes rough machined with stock conditions and configurations as shown in (Figs. 1 and 4) were obtained and prepared for high speed abrasive machining tests. The forms to be produced are illustrated in (Figs. 2 and 5). This allows for a total average depth of grind of approximately .520 inches average. Total stock to be removed will amount to approximately 29 cubic inches. Figs. 3 and 6 are inspection reports of a 105mm M68 and a 105mm How M2A2. Dimensions shown are well within the component specification tolerances.

Partial tooling used for experimental crush form grinding tests on both the 105mm M68 and the 105mm How M2A2 consisted of a solid tapered plug type fitted to the tube taper on the 4.356" bore diameter at the breech end. The plug was incorporated with a driving slot to accommodate the work head drive pins. Problems were experienced in removing the solid plug from the bore after grinding. The solid plug was modified to a split type eliminating the plug siezing problem. For production set up a split expanding plug that can be collapsed for ease in removal is recommended. A fixed outboard roller rest was used to support the gun tube on the various diameters as illustrated in Fig. 7. We found that the steady rest diameters were not necessarily concentric with the bore centerline and consequently the diameters as ground may not run true with the bore diameters as specified. For test purposes this set-up was satisfactory; for future production set ups a tailstock must be provided to support and retain the rotating gun tube at the muzzle end. In this way the gun tube will be located on the bore centerline and the diameters to be abrasive crush form ground will be concentric with the bore center line.

### Grinding Results

Ten tests were conducted to determine the "optimum" feed and speeds to grind the part while remaining with the limited horsepower capabilities of the experimental set up. The "Process Data", Appendix A, gives the complete machine set up as determined while grinding all gun tubes. The projected floor to floor cycle time was broken down as follows:

| | Time (Minutes) |
|---|---|
| Load | 10 |
| Fast Feed Grind | 28 |
| Slow Feed Grind | 20 |
| Dwell | 1 |
| Unload | 10 |
| Total | 69 Minutes |

Original engineering called for a 26-28 minute total cycle time based on operating at 11,000 sfpm. However, because of such long lead times required by manufacturers (6 months) for grinding wheels and the lack of sufficient horsepower, it was decided to expedite matters by using a wheel from inventory along with the converted equipment. The wheel selected was one designed to operate at a maximum of 7,000 sfpm; consequently slower cycle time resulted. Workhead and wheelhead motor load seemed to be the limiting factor in determining infeed rates. Tables 1 and 2 below show the results of experimentation to determine optimum fast and slow feed rates. In both fast and slow feed, occasional overload resulted.

TABLE 1. FAST FEED TEST DATA (AVERAGES)

| Test | Feed Rate (in/min) | Stock/Rev. (In/Rev.) | Stock Removal Rate ($In^3$/Min) | Workhead Motor Load % | Wheelhead Motor Load % |
|---|---|---|---|---|---|
| 1 to 10 | 0.040 | 0.00080 | 1.889 | Overload | 70 |
| 10 to 15 | 0.030 | 0.00060 | 1.460 | 100 | 50 |
| 15 to 20 | 0.015 | 0.00030 | 0.708 | 50 | 30 |

TABLE 2. SLOW FEED TEST DATA (AVERAGES)

| Test | Feed Rate (in/min) | Stock/Rev. (In/Rev) | Stock Removal Rate ($In^3$/min) | Workhead Motor Load % | Wheelhead Motor Load % |
|---|---|---|---|---|---|
| 1 to 12 | 0.00015 | 0.00015 | 1.918 | 100 | 70 |
| 12 to 20 | 0.005 | 0.00010 | 1.199 | 70 | 40 |

The workhead and wheelhead motor loads shown in test 1 and 2 are not steady state values but are averages of all conditions. Peaks were experienced when the wheel first contacted the rough turned part surface. This is attributed to the out of round condition of the turned surfaces. Therefore, it was necessary to allow some margin in workhead motor overload for the possibility of these peaks occurring. Grind depths were set up in such a manner that the slow feed mode began when full wheel contact was made thus utilizing fast feed grind to its greatest advantage when wheel to part contact is small. Due to the large amounts of stock to be removed and significant wheel wear observed, the following grind procedure was followed during experimental tests.

a. Rough grind to within .005" of finish size.

b. Recrush the wheel.

c. Grind to finish size.

d. Use wheel to rough next part before recrushing.

Work speed was set to achieve 125 surface feet per minute. This was an attempt to establish the optimum wheel to work ratio ranges between 50-60 to 1 as was previously discussed.

One parameter that can be gaged to determine optimal grinding conditions is stock removal per revolution. Satisfactory results for most steels can be obtained by operating fast feed in the .0003" to .0006" range and slow feed in the 0 to .0002" range. Slow stock removal was established at .0003"/rev. and .0001"/rev. respectively. These values seemed to work well and did produce good machine performance and part quality.

The second part was used to judge wheel wear, and the effects of coolant supply and performance of the Jet Wheel Cleaner for determination of horsepower requirements. Wheel wear seemed to be significant. Tests showed that wear amounted to an average of .009" (radial) per .100" infeed. This was attributed to three primary factors: (1) Improper wheel selection, (2) the lack of sufficient torque and horsepower and (3) wheel speed. Coolant flow of 30 gallons per minute for the experimental application seemed to be adequate i.e., no excessive burning of the test component was visible. However, coolant flow of 150 gallons per minute will be required on the future machine to produce full form grinding. Use of a 10 horsepower jet wheel cleaner designed to operate at 10,000 pounds per square inch, oscillating across the wheel for wheel cleaning was an absolute necessity.

Since wheel wear seemed excessive and did amount to a high average (approximately .009") it is recommended that a coarser, harder or even multi grade wheel be used. It is felt that the harder, coarser wheel will reduce wheel wear while maintaining dimensional accuracy and surface finish. Although multi grade wheels were used during some of the test phases, only limited data was obtained. It is felt that this limited data was insufficient to plot for conclusion. Further testing to determine multi grade systems will be necessary. For high speed abrasive machining a Bendix wheel 18A60"0"5V124 (industrial code) is recommended as a starting grade. Only extensive testing will determine the most satisfactory composition for use with present gun or cannon materials. A ratio of wheel life to cubic volume removed as a function of time will be the determining factors for final wheel acceptance. Testing of this nature is planned for the second phase of the program, i.e., after procurement and assembly of the future capital equipment.

PROCESS DATA

EXPERIMENTAL CRUSH FORM ABRASIVE MACHINING

TEST SUMMARY

| | | |
|---|---|---|
| PART NAMES | | 105MM HOW M2A2 Tube<br>105MM M68 Tube |
| PART NUMBER | | D7238068<br>D8765961 |
| MACHINE | | Bendix Model 187C<br>Converted for Test |
| WHEEL: | SIZE | 24" O.D. x 9" W. x 12.000 I.D. |
| | SPEC. | Bendix Abrasive 18A120M5V124 |
| | SPEED | 7000 sfpm |
| CRUSH ROLL | | Tungsten Carbide |
| COOLANT | | Metgrind WV2 |
| FILTRATION | | Delpark Filtermatic #8-9 x 36 |
| REFRIGERATION | | Hansen 10 H.P. Air Cooled |
| MIST COLLECTION | | None |
| WHEEL CLEANER | | Bendix Super Jet Wheel Cleaner<br>7-1/2 H.P. |
| WORK SPEED | | 125 sfpm (52 rpm) |
| GRIND DEPTH | | .520" total - .420" fast, .100" slow |
| GRIND INFEED RATE | | .015 in/min. fast, .005 in/min. slow |
| GRIND DWELL | | 60 Seconds |
| GRIND CYCLE | | 49 Minutes |
| CRUSH DEPTH | | .010" |
| CRUSH RATE | | .003 in/min. |
| CRUSH DWELL | | 20 Seconds |
| CRUSH CYCLE | | 4 Min. |

PROCESS DATA

EXPERIMENTAL CRUSH FORM ABRASIVE MACHINING

PROPOSED METHOD

| | |
|---|---|
| PART NAME | 105MM HOW M2A2 Tube<br>105MM M68 Tube |
| PART NUMBERS | D7238068<br>D8765961 |
| MACHINE | Specification RS-6-76<br>150 H.P. |
| WHEEL: SIZE | 42" O.D. x 12" W. x 20" I.D. |
| SPEC | Bendix Abrasive 18A70"0"5V124<br>(This is not positively established) |
| SPEED | 7000 to 11,000 SFPM |
| CRUSH ROLL | Boron Carbide |
| COOLANT | Metgrind WV2 |
| COOLANT CAPACITY (PUMP) | 150 Gallons per minute @150 lbs per square inch. |
| FILTRATION | Delpark Filtermatic #8-9 x 36 |
| MIST COLLECTION | Smog Hog - 2400 cfm |
| REFRIGERATION | Hansen 25 H.P. Air Cooled |
| WHEEL SPEED | 620 to 800 RPM |
| WHEEL CLEANER | Bendix Super Jet Wheel Cleaner<br>15 HP |
| WORK SPEED | 16 to 38 RPM |
| GRIND DEPTH | .520" total - .420" fast, .100" slow |
| GRIND INFEED RATE | .031 in/min. fast, .010 in/min. slow |
| GRIND DWELL | 10 Seconds to 60 Seconds |
| GRIND CYCLE | 20.0 minutes |
| CRUSH DEPTH | .010" in/min |
| CRUSH RATE | .003 in/min |

PROCESS DATA (Continued)

EXPERIMENTAL CRUSH FORM ABRASIVE MACHINING

PROPOSED METHOD

| | |
|---|---|
| CRUSH DWELL | 20 Seconds |
| CRUSH CYCLE | 4 Minutes |
| TAIL STOCK PRESSURE | 50 PSI Minimum |

MANUFACTURING COST ANALYSIS

EXPERIMENTAL CRUSH FORM ABRASIVE MACHINING

PT. No. D7238068 NAME - 105MM HOW M2A2 TUBE

PT. No. D8765961 NAME - 105MM M68 TUBE

| DESCRIPTION | TIME (Min.) | TIME PER 10 PIECES | TIME PER 100 PIECES |
|---|---|---|---|
| Mounting the Wheel | 45 | 45 | 45 |
| Mounting the Crusher Roll | 20 | 20 | 20 |
| Dressing the Periphery | 10 | 10 | 10 |
| Crushing a New Wheel | 135 | 175* | 535* |
| Mounting & Indicating Tools | 20 | 20 | 20 |
| Set Up Machine Cycle | 10 | 10 | 10 |
| Machining Cycle | 49 | 490 | 4900 |
| Part Handling | 20 | 200 | 2000 |
| | 309 | 970 | 7540 |

Average Grinding Time -- 49 Min. per piece.

This figure is based on test grinding only and does not allow for any personnel allowances.

*Includes 4 Min. Recrush After Every Part.

# COMPUTATION

COMPONENT ______ BY: ______

DRAWING ______ DATE ______

OPER. NO. ______ DIVISION ______

MACHINE ______ MATERIAL & HARDNESS ______

MINIMUM RAD. ______

WHEEL SPECS. ______ RMS REQ'D ______

TOTAL DEPTH OF GRIND ______ PART DIA. ______

PART CIRCUMFERENCE (DIA. X) ______

PART CIRCUMFERENCE IN FT. $\left(\frac{\text{Circum. in inch.}}{12}\right)$ ______

SFM OF PART (125 STD.) ______

RPM OF WORKHEAD $\left(\frac{\text{SFM}}{\text{Part Circum. in Ft.}}\right)$ ______

STOCK REMOVAL/REV. ( .0002 STD. ) ______

Slow Grind Fast Grind

STOCK REMOVAL / MINUTE (RPM OF W. H. X STK. REMOVAL/REV.) ______

GRINDING TIME IN MINUTES $\left(\frac{\text{Depth of Gr.}}{\text{STK. of Removal/Min.}}\right)$ ______

GRINDING TIME IN SECONDS (GR. TIME IN MIN. X 60) ______

STOCK REMOVAL/MINUTE (RPM OF W. H. x STK. REMOVAL/REV.) ______

GRINDING TIME IN MINUTES $\left(\frac{\text{Depth of Gr.}}{\text{Stk. Removal/Min.}}\right)$ ______

GRINDING TIME IN SECONDS (Gr. Time in Min. x 60) ______

## CYCLE TIME

LOADING ______

UNLOADING ______

RAPID APPROACH ______

RAPID RETRACT ______

FAST GRIND (______ Per Minute/Second) ______

SLOW GRIND (______ Per Minute/Second) ______

DWELL ______

INDEX ______

TOTAL CYCLE IN MINUTES ______ SEC. ______

PARTS/HR. @ 100% EFF. ______

MANUFACTURING COST ANALYSIS

PROPOSED METHOD

PT. No. D7238068 NAME -- 105MM HOW M2A2 TUBE

PT. No. D8765961 NAME -- 105MM M68 TUBE

| DESCRIPTION | TIME (Min) | TIME PER 10 PIECES | TIME PER 100 PIECES |
|---|---|---|---|
| Mounting the Wheel | 45 | 45 | 45 |
| Mounting the Crusher Roll | 20 | 20 | 20 |
| Dressing the Periphery | 10 | 10 | 10 |
| Crushing a New Wheel | 135 | 175* | 535* |
| Mounting & Indicating Tools | 20 | 20 | 20 |
| Set Up Machine Cycle | 10 | 10 | 10 |
| Machining Cycle | 24.5 | 245 | 2450 |
| Part Handling | 20 | 200 | 2000 |
| | 284.5 | 725 | 5090 |

Average Grinding Time -- 24.5 Min. per Piece

This figure is based on test grinding only and does not allow for any personnel allowances.

*Includes 4 Min. Recrush After Every Part.

## PROJECTED COST SAVINGS

### *CURRENT METHOD - MACHINE TURN - CARBIDE TOOLS

| TUBE | OPER. # | AVG. MACH TIME EA. | AVG. OPER. COST ** |
|---|---|---|---|
| 105mm M68 | 230 | 1.5 | $37.50 |
| 155mm M185 | 230 | 2.0 | 50.00 |

### PROPOSED METHOD - CRUSH FORM GRIND

| TUBE | OPER.# | AVG. GRIND TIME EA. | AVG. OPER. COST** | SAVINGS PER TUBE |
|---|---|---|---|---|
| 105mm M68 | 230 | .5 | $12.50 | $25.00 |
| 155mm M185 | 230 | .5 | $12.50 | $37.50 |

* Current Method - The manufacturing method in use at the time of Project P-16 submission. Installation of N.C. equipment or automated processes may modify these figures.

**Based on applied overhead rate of $25.00 per hour.

# LOCATION OF FIGURES

COMPONENT CONDITION PRIOR TO EXPERIMENTAL ABRASIVE MACHINING OF BREECH END OF TUBE

SCALE 1/10

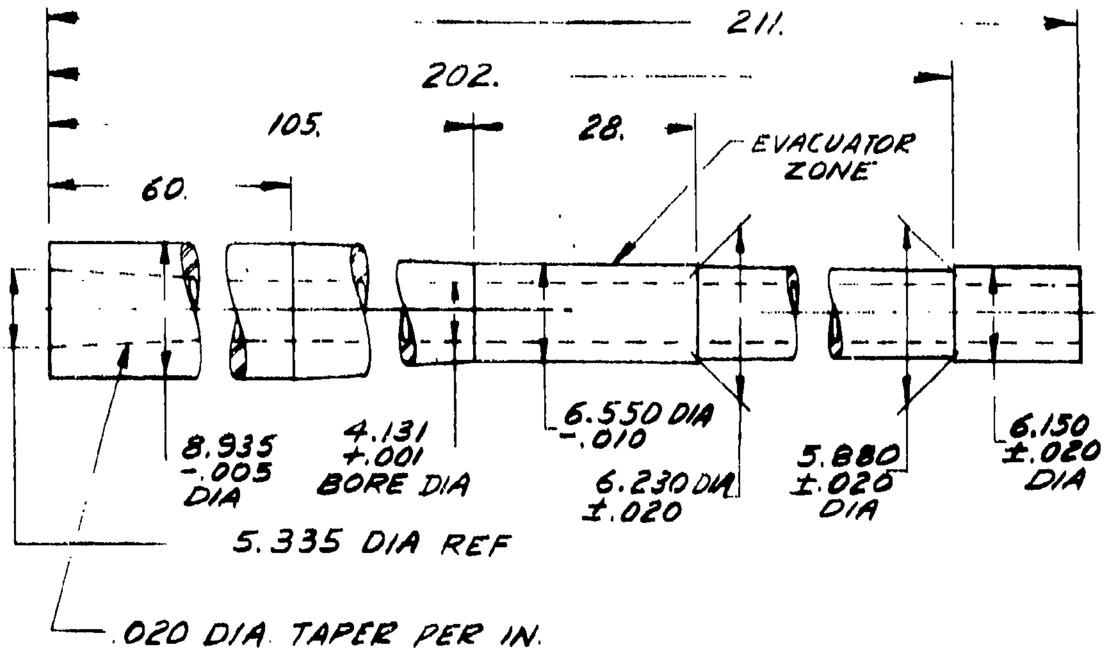
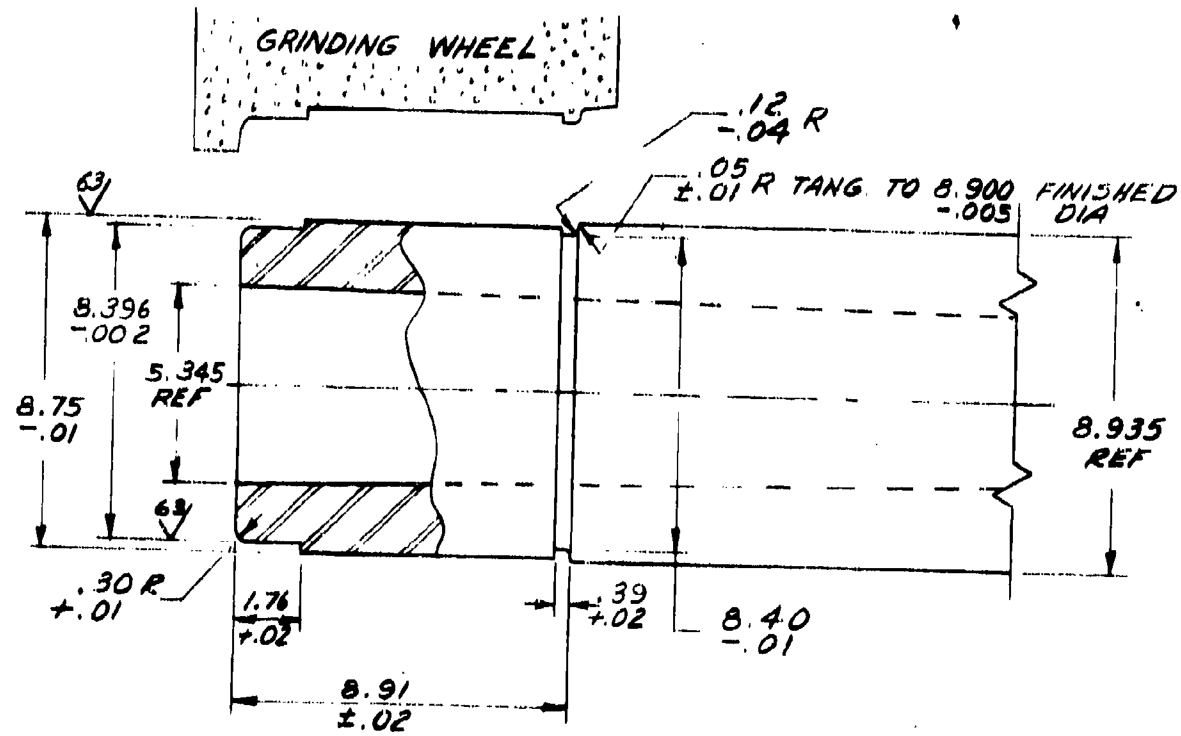



FIG. 1

DIMENSIONS TO BE PRODUCED BY
EXPERIMENTAL ABRASIVE MACHINING

SCALE $\frac{1}{4}$




UNLESS SPECIFIED: BREAK EDGES .015 MAX., FILLETS .02R-.01, FINISH 125

PRESENT METHOD

4 TOOLS USED
MACHINING TIME = 1.5 HOURS

PROPOSED METHOD

34 CU. IN REMOVED = 9.52 LBS
EST. MACHINING TIME = .5 HOURS MIN.

FIG. 2

# INSPECTION REPORT
## HIGHSPEED ABRASIVE MACHINING
## 105MM M-68

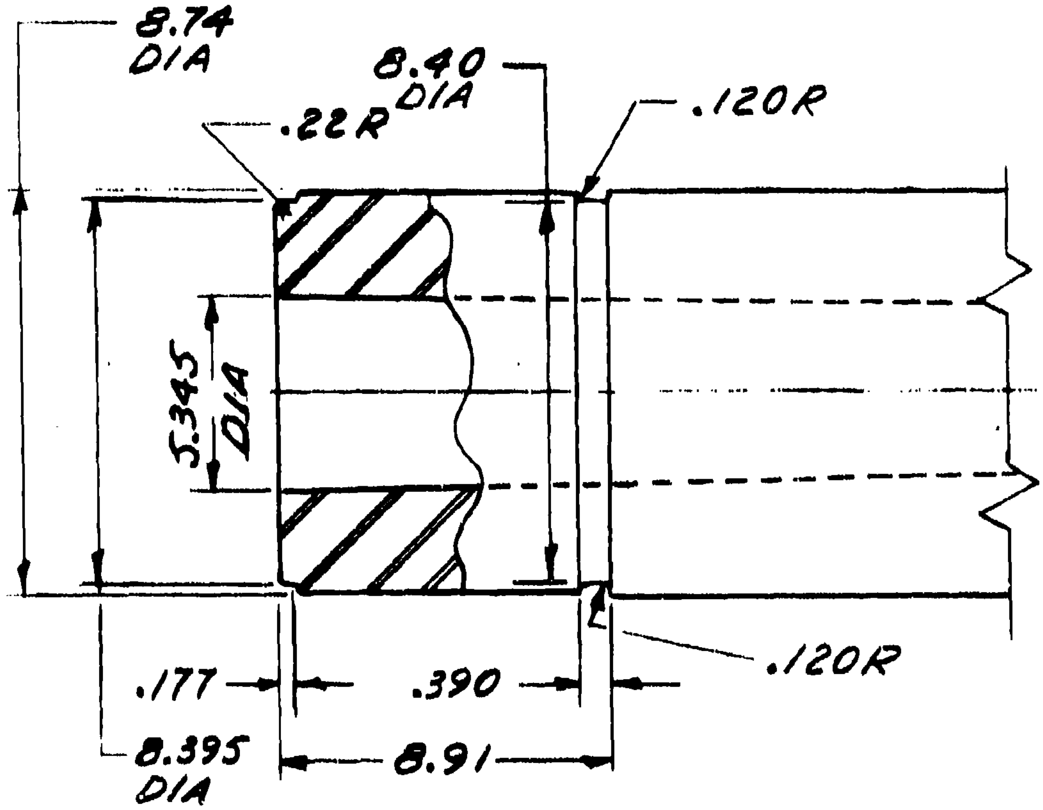



FIG. 3

COMPONENT CONDITION PRIOR TO
EXPERIMENTAL ABRASIVE MACHINING

SCALE $\frac{1}{10}$

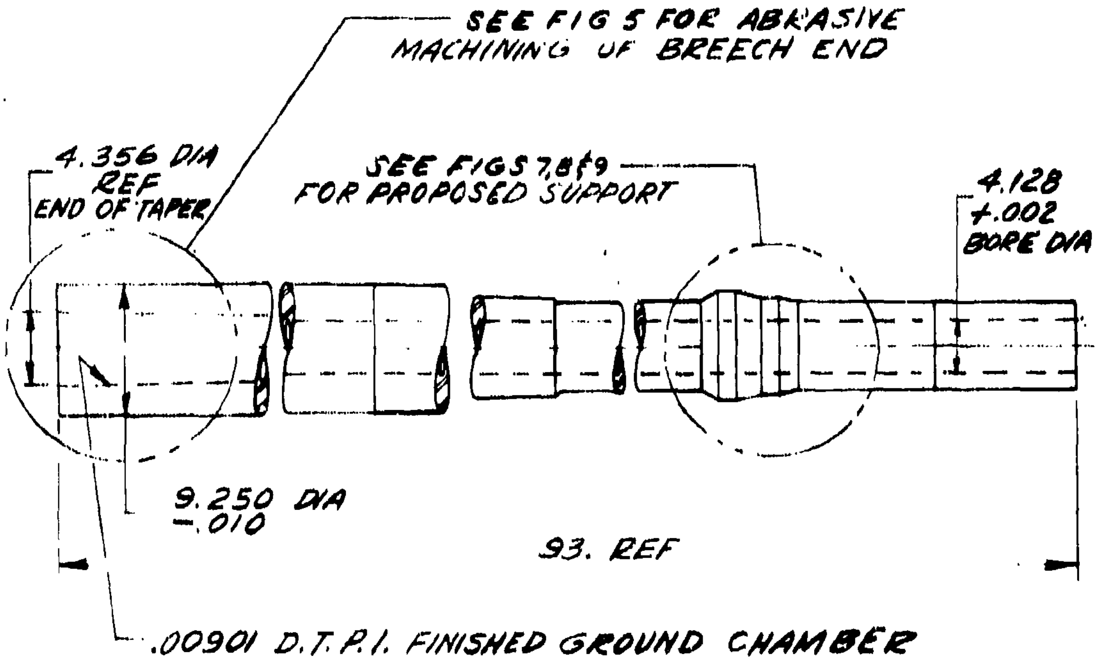
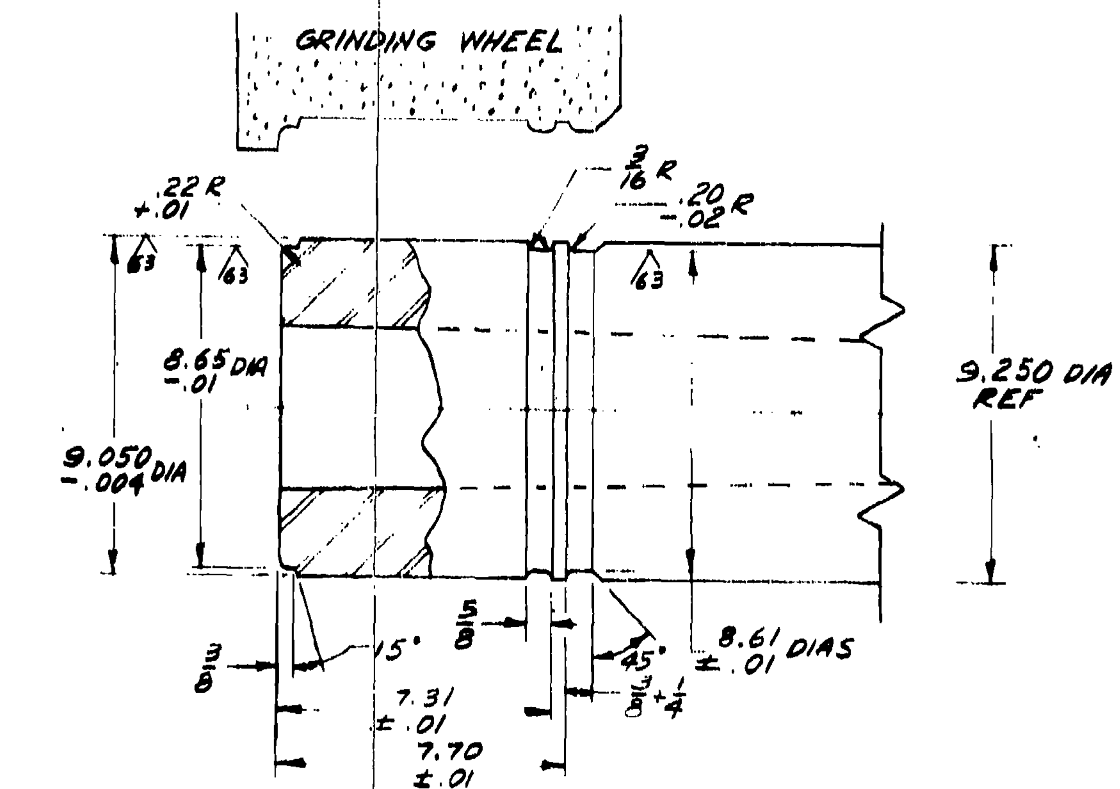



FIG. 4

DIMENSIONS TO BE PRODUCED BY EXPERIMENTAL ABRASIVE MACHINING

SCALE $\frac{1}{4}$




UNLESS SPECIFIED: BREAK EDGES .015 MAX, FILLETS .05 R-.01, FINISH 125

<u>PRESENT METHOD</u>

5 TOOLS USED
MACHINING TIME 1.7 HOURS

<u>PROPOSED METHOD</u>

29. CU. IN REMOVED = 8.12 LBS
EST. MACHINING TIME = .5 HOURS MIN.

FIG. 5

INSPECTION REPORT
HIGH SPEED ABRASIVE MACHINING
105MM M2A2

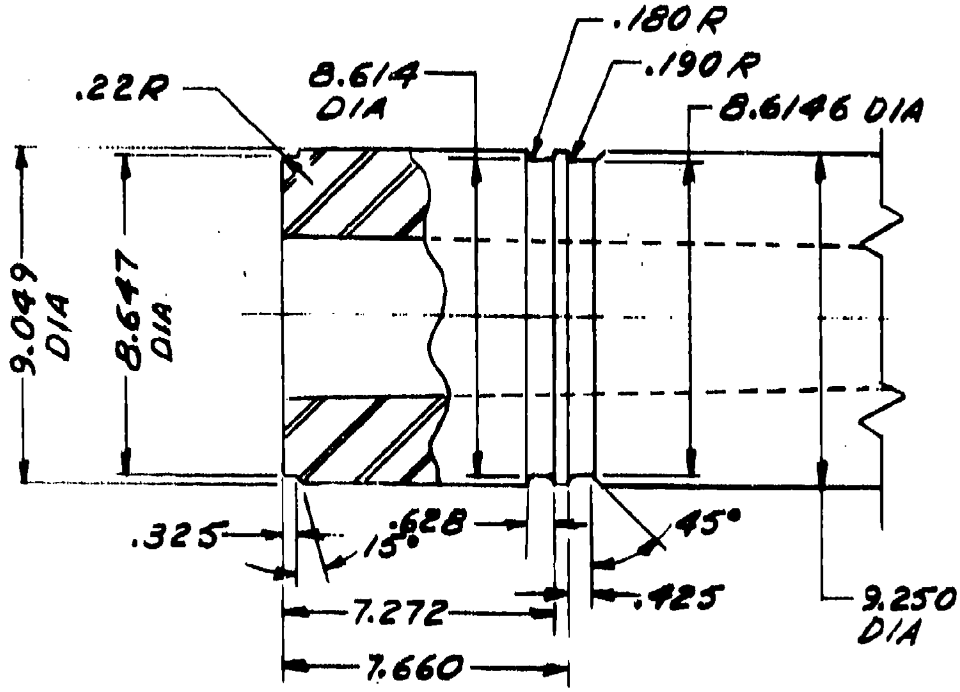
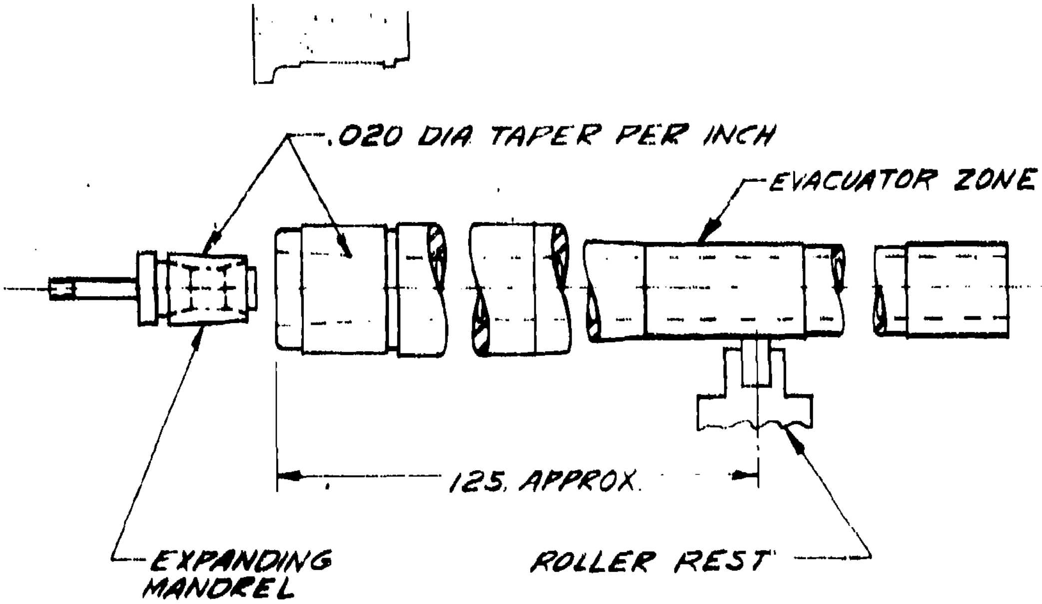



FIG. 6

PROPOSED METHOD OF EXPERIMENTAL
ABRASIVE MACHINING OF BREECH END
SCALE $\frac{1}{4}$




32 CU. IN. OF METAL REMOVED = 9.6 LBS
EST. MACHINING TIME = .5 HOURS

FIG. 7

## TEST EQUIPMENT

MODIFIED MODEL 187A MULTIFORM GRINDER WITH HEAVY DUTY ROLL GRINDER WORKHEAD, SPECIAL PLATEN WITH (2) JOURNAL SUPPORT-TYPE STEADY RESTS. 75 H.P. WHEELHEAD SPINDLE DRIVE.

## PRODUCTION ESTIMATE

28 MINUTES GRINDING TIME INCLUDING SPARKOUT BUT NOT INCLUDING LOAD OR UNLOAD

FINISH CRUSH GRIND THE COMPLETE BREECH DIAMETER CONFIGURATION AS SHOWN IN ONE OPERATION ON THE 105MM M68 GUN TUBE

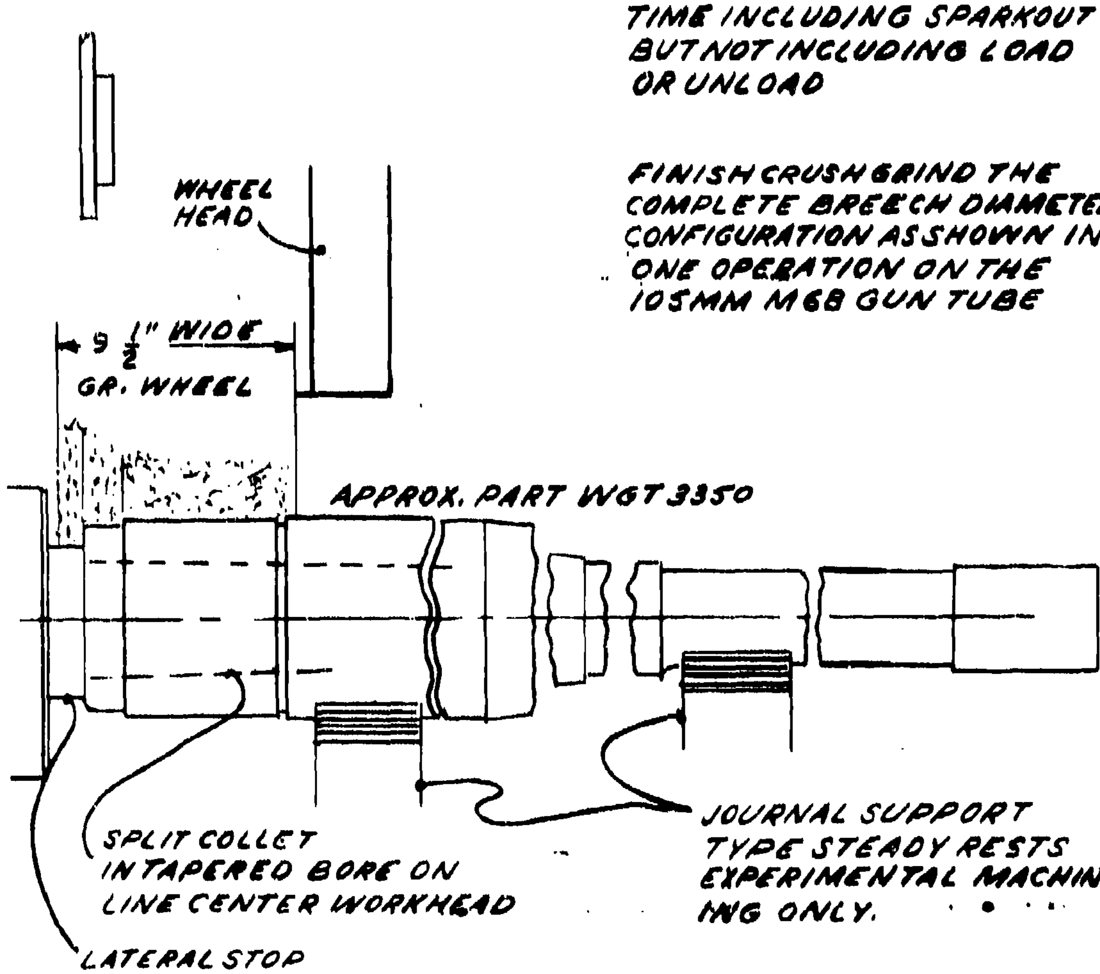



FIG. 8

## TEST EQUIPMENT

MODIFIED MODEL 187A MULTI-FORM GRINDER WITH HEAVY DUTY WORKHEAD. SPECIAL PLATEN WITH (2) JOURNAL SUPPORT TYPE STEADY RESTS. 75 H.P. WHEELHEAD SPINDLE DRIVE.

## PRODUCTION ESTIMATE APPROXIMATE

26-28 MINUTES GRIND TIME. 100% EFFICIENCY IS BASED ON REMOVING APPROXIMATELY 29 CUBIC INCHES OF STOCK: 8.1218 AS PER SKETCH AE 30, SH2.

FINISH CRUSH GRIND THE COMPLETE BREECH DIA CONFIGURATION AS SHOWN IN ONE OPERATION ON THE 105MM HOW, M2A2

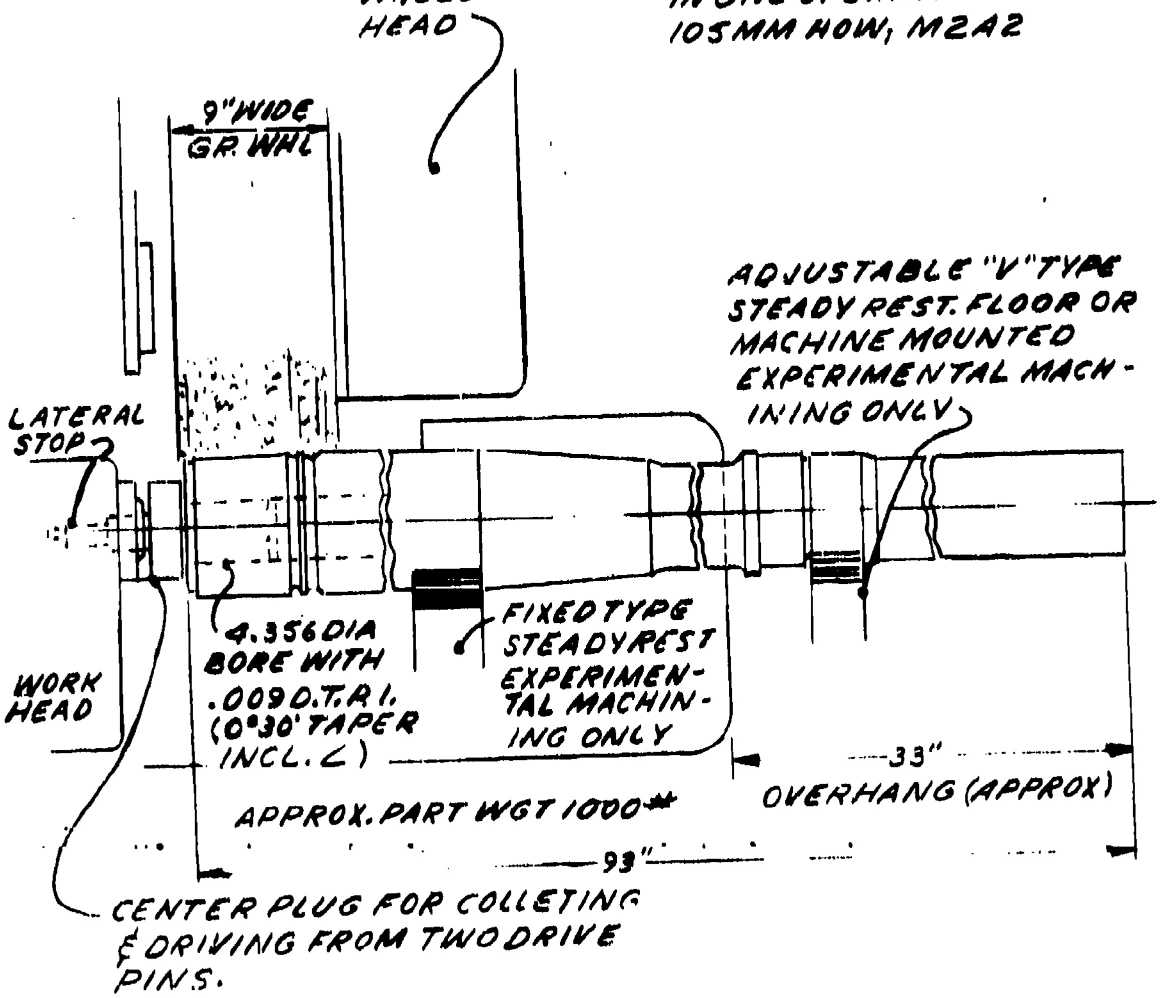



FIG. 9

# APPENDIX B

## SPECIFICATION RS-6-76

U. S. ARMY
WATERVLIET ARSENAL, WATERVLIET, N. Y.
ADVANCED ENGINEERING DIVISION
BENET WEAPONS LABORATORY

U.S. Army
Watervliet Arsenal, Watervliet, N.Y.
Advanced Engineering Division
Benet Weapons Lab. SPEC RS-6-76
John Rodd/5611 15 Dec 1976

## Machine Automatic External Multiform Abrasive Crush Grinder

1. Scope:

1.1 This specification covers one size and type experimental automatic external annular multi form crush grinding machine capable of producing the finished exterior configuration as required on a variety of gun tubes by multiform abrasive wheels. Ordnance components will range in hardness from Rockwell "C" 35-45.

1.1.1 The automatic abrasive crush form grinding machine covered by this specification shall be of sufficient size and capacity to adequately rough, semi-finish and finish grind gun tubes listed herein to the configurations and surface finishes specified, completing each configuration, removing the maximum amount of metal in the floor to floor time specified.

1.1.2 The machine shall be capable of supporting and grinding specific areas of various gun tubes. Gun tubes will vary in length from approximately (90) inches long up to approximately (260) inches long. Gun tubes will vary in breech diameter from approximately (7) inches in diameter up to approximately (13) inches in diameter. Gun tubes will vary in weight from approximately 1000 pounds each to approximately 6000 pounds each.

1.1.3 The specified length and weight of gun tubes selected for finish abrasive machining are cited in paragraph 1.1.2 and by engineering drawings specified in paragraph 1.1.6. In addition, floor to floor time allotted for abrasive machining each component is specified in paragraph 1.1.6.

1.1.4 Each component shall have a set of carbide crush rolls and abrasive wheels specifically designed to perform with their specification requirement. These items shall become part of the machine equipment and are required to perform in accordance with this specification.

1.1.5 Mandatory Machining Requirements: The machine and all related components and equipment shall be capable of continuously grinding ordnance components to the specifications described in the below component specifications, paragraph 1.1.6 without deviation.

1.1.6 Component Specifications:

a. 105mm M68 Gun Tube Drawing D8765961 Operation 230 (Breech Thread Blank Diameters, Pilots, reliefs and associated areas)

Mandatory maximum floor to floor time per gun tube (abrasive machining) 1.0 hrs.

b. 155mm M185 Gun Tube Drawing F11578388, Operation 230 (Breech Thread Blank Diameters, Pilots, reliefs and associated areas).

Mandatory maximum floor to floor time per gun tube (abrasive machined) 1-1/2 hrs.

1.1.7 Components Furnished for Preliminary Test: Three (3) each 105mm M68 gun tubes D8765961 semi finished machined up to operation 230 and three (3) each 155mm M185 gun tubes F11578388 semi finished machined up to operation 230 shall be furnished to the contractor by Watervliet Arsenal for preliminary test, to establish abrasive machining parameters and floor to floor times in accordance with Paragraph 1.1.6.

1.1.8 Government-Owned Property: The above items specified in paragraph 1.1.7, all government owned property, will be forwarded to the contractor's plant or test facility to be used as set-up components for experimental abrasive machining test. Each component configuration shall, after abrasive machining, conform to all drawing and routing requirements and tolerances specified on that particular engineering drawing without deviation. All mandatory requirements shall be met without exception.

1.1.9 Component Scrap: A percentage for scrap of any gun tube furnished for any phase of abrasive grinding testing shall not be tolerated. Responsibility for scrap of any government owned property as specified in paragraph 1.1.7 shall be 100% of the individual cost and this cost shall be solely the responsibility of the contractor. Component costs have been established individually for each gun tube. These costs are specified as follows:

| | | Cost Each Tube |
|---|---|---|
| a. | 105mm M68 Gun Tube Forging Drawing D8765839 | $3,000 |
| b. | 155mm M185 Gun Tube Forging Drawing F11578386 | $5,500 |

1.1.10 Component test: In process and final inspection reports shall be furnished by the contractor of each component machined. Reports shall show all dimensions and surface finish obtained. In addition, component inspection reports shall show floor to floor time in which the component was machined. Component test shall be conducted at the plant of the contractor in the presence of Watervliet Arsenal Advanced Engineering Division personnel. The contractor shall inform Watervliet Arsenal of dates of test at least 14 days prior to test so that necessary preparations can be made by Watervliet to be present.

2. Applicable Documents:

2.1 Paint color: In accordance with Federal Standard #595, color gray #16187 or gloss medium gray #123 as listed in color card supplement to Federal Standard #141. Copies may be obtained from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

2.2 Electrics: Electrics shall be in accordance with Machine Tool Builders Electrical Standards, adopted by the National Machine Tool Builders Association, 25 January 1960 and the latest revision thereto, or JIC Electrical Standards for general purpose machine tools. Copies may be obtained from National Machine Tool Builders Association, 2139 Wisconsin Avenue, N.W., Washington, D.C. 20007.

2.3 Military Publications:

Specifications

MIL-M-18058 Machinery Metal and Woodworking, Support Equipment and Associated Repair Parts, Preparation for Delivery of

Standards

MIL-STD-129 Marking for shipment and storage

MIL-STD-130 Identification Marking for U.S. Property

2.4 American Standards Institute Publications:

USAS B5.1 T-Slots, Their Bolts, Nuts,Tongues and Cutters

USAS B5.28 Lubrication & Coolant Pumps for Machine Tools Mounting Dimensions

Application for copies should be addressed to United States of America Standards Institute, 10 East 40th Street, New York, N.Y. 10016.

2.5 American Gear Manufacturers Association

AGMA 360.01 Manual for machine tool gearing (Application for copies should be addressed to United States of America Standards Institute, 10 East 49th Street, New York, New York 10016).

2.6 Threads: In accordance with National Bureau of Standards Handbook H-28 "Screw Thread Standards for Federal Services". Copies may be obtained from Superintendent of Ducuments, U.S. Government Printing Office, Washington, D.C. 20402.

3. Requirements:

3.1 General Requirements:

3.1.1 Material: Material to be used in the construction of the machine shall be sound, of uniform quality and condition, and shall conform in composition, heat treatment and suitability to the standard practices of reputable machine tool manufacturers.

3.1.2 Design: The design shall be, such as to provide convenient and safe operation. All parts shall be now, designed and constructed to the requirements listed herein. All parts subject to wear or breakage shall be easily accessible for adjustment, replacement and repair. The machine shall be capable of crush grinding to tolerances of .001". The machine shall be of the manufacturer's latest improved design and shall be provided with all modern production features so that every type of annular form grinding operation may be performed automatically and manually as desired with a high degree of accuracy, flexibility, utility and safety acceptable in the best industrial practices. The design shall show flexibility in that the machine can utilize either a dead center or live center work head as desired, based on the maximum work load support requirements at any particular time.

3.1.3 Safety Devices: The machine shall be equipped with covering for all parts that present safety hazards to the operator or any of the equipment. All guards and covers shall conform to OSHA standards and shall provide easy access to the guarded parts and shall not interfere with machine operation. The electrical system shall be grounded in accordance with OSHA standards.

3.1.3.1 Operating Controls: Controls for all functions of the machine shall be arranged in a location convenient to the operator.

3.1.4 Lubrication: Means shall be provided to deliver lubricant to all parts such as enclosed bearings (except sealed-for-life type), gears and shafts, sliding components and guide ways. Automatic systems shall be metered pressure type or flood type, or a combination of these types arranged to insure adequate lubrication of the parts. Recirculating systems shall be equipped with means for filtering the lubricant. Each lubrication reservoir shall have means for determining oil level.

3.1.5 Construction: All parts and materials used in the construction of the machine shall be new. The quality shall be such as will provide the strength, rigidity and wear resistant characteristics necessary to insure conformance to the standards for construction, accuracy, performance and safety requirements specified herein. All parts subject to adjustment, repair or replacement shall be readily accessible.

3.1.6 Welding, brazing or soldering: Welding, brazing or soldering shall be employed only where included in the original design. None of these operations shall be employed as a repair measure for any defective part.

3.1.7 Fastening devices: All screws, pins, bolts, and similar parts

shall be installed with means for preventing loss of tightness and adjustment where design requires. All such parts when subject to removal or adjustment shall not be swaged, peened, staked or otherwise permanently deformed.

3.1.8 Threads: All threaded parts shall be in the inch system conforming to Handbook H28.

3.1.9 Dials: All feed dials shall be graduated in both the inch and metric systems. Graduations to depict stock removal or tool movement shall be in increments of not more than .0005 inch. Dial diameters shall be such that the graduations may be easily read. Dials shall be permanently and legibly engraved, or etched, and shall have a non-glare finish. Dials shall have a means of convenient setting.

3.1.10 Plates: All words on speed and feed indicating plates and on instruction plates shall be in the English language, using bold face lettering. All characters shall be permanent and legible on a contrasting background.

3.1.11 Gears: All gearing used in the machine and its components shall be machined in the inch system, and shall conform to the applicable requirements of AGMA 360.01.

3.1.12 Interchangeability: All replacement parts shall be manufactured in the inch system to definite standards, tolerances, and clearances, in order that any such parts of a particular type or model may be replaced or adjusted without requiring modification or fitting operations.

3.1.13 Surfaces: All surfaces of all castings, forgings, molded parts, stampings and welded parts shall be cleaned and free of sand, dirt, fins, sprues, scale, flux, flash and other harmful or extraneous materials.

External surfaces shall be smooth and all edges shall be either rounded or beveled, unless sharpness is required to perform a necessary function.

3.1.14 Castings and Forgings: All castings and forgings shall be of uniform quality, stress relieved before final machining, free from defects such as mismatching at joints, blow holes, porosity, hard spots, shrinkage defects, cracks or other injurious defects. Strength and other physical properties of the casting or forging shall be adequate throughout, for the purpose intended. In no event shall processes such as peening, plugging or filling with cold solder or metallic pastes and glues be used on castings or forgings for reclaiming any parts of the machine without written authorization from the government.

3.1.15 Painting:

3.1.15.1 Preparations of Surfaces: All surfaces to be painted, shall be thoroughly cleaned of all grease, oil, scale, rust, dirt and other extraneous matter.

3.1.15.2 General Application: Primer, filler, sealer, enamel, or lacquer used shall be applied in such a manner as to provide a surface of high quality appearance, free from runs, sags, cracks, flaking, peeling, bleaching and other defects which may affect drying characteristics, durability and appearance of the painted surfaces. Primer, enamel or lacquer may be applied by either brush or spray.

3.1.15.3 Basic Application: Surfaces of the machine for which a painted surface is suitable, shall have such surfaces finished with one or more coats of primer having good adhesive and rust resistant properties. The final application shall include a satisfactory filler, smoothly finished

and sealed, followed by not less than two coats of good quality, high gloss enamel or lacquer. Color shall be #123 gray as specified in color card supplement to U.S. Army Specification #141, or in accordance with Federal Standard #595, color gray #16187.

3.1.16 Equipment, Instructions and Operations:

3.1.16.1 The machine shall be provided with all equipment, tools and accessories normally supplied as standard.

3.1.16.2 The contractor shall furnish with the machine, in triplicate, repair parts catalogs, foundation drawings and specifications, installation drawings, wiring diagrams and operator instruction manuals for the proper installation, operation and lubrication of the machine and all associated peripherial support items or hardware. In addition to the above, foundation drawings or specifications and installation instructions shall be forwarded to Watervliet Arsenal 60 days prior to shipment of the machine.

3.1.16.3 A lubrication chart or plate shall be securely attached to the machine. If a chart is furnished, it shall be placed in a transparent plastic folder or laminated between clear, plastic, permanent sheets with suitable means for mounting. The following information shall be furnished on the chart or plate: Points of lubrication, both concealed and visible, service interval, type of lubricant and viscosity. The contractor shall furnish complete specifications for use in competitive bidding, of special lubricants used in the lubrication of the machine.

3.1.16.4 Machine and control system components which are not manufactured by the contractor and, which are available from other commercial sources, shall be identified in parts lists furnished with the machine by the name of the original manufacturer, description of component, and catalogue model or part number. The contractor shall also furnish a competent service

engineer to place the machine in proper operation, instruct operators in the proper operation and complete orientation in the general overall application of the machine. These services shall be performed during the hours of 8:00 AM to 4:00 PM on regular Arsenal workdays, Monday through Friday, unless otherwise approved by this Arsenal. These services shall terminate when the machine and accessories are accepted by Watervliet Arsenal.

3.1.16.5 Upon receipt of the machine, Watervliet Arsenal will run utilities (air & electric) to the machine, install basic machine on foundation and install major components under the supervision and guidance of attending factory representatives.

3.1.16.6 Training: The contractor shall provide training of Arsenal personnel in maintenance (both mechanical and electrical). The training shall be performed at Watervliet Arsenal during and subsequent to the machine installation by the contractor's service technician. Training shall be provided to a minimum of two maintenance men and shall be for a period of not less than 5 working days or 40 work hours.

3.2 Detailed Requirements: The proposed machine shall be new, of the latest type and design, embodying proven principles of construction with inbuilt rigidity to perform at maximum efficiency under full load, free from undesirable vibration and deflection.

The machine shall be fully equipped with all required electrical circuits, motors, control panels, and wiring to safely and efficiently operate the machine throughout its full range and capacity.

The machine shall be free from any characteristics or defects that would render the machine unsuitable or inefficient for its intended

purpose and shall be complete so that when installed and connected to the power source, it can be used to its full range and capacity for any operation for which it was designed. The machine shall be completely automatic in all its functions with provisions for override to manual in the event manual operation is desired during the automatic cycle. The machine shall be fully automatic except for placing the workpiece in the machine, removing the finished product from the machine and actuating the repeat cycle control mechanism. The machine shall be capable of grinding to a predetermined size and surface finish, dwell if required and stop automatically without manual adjustment of the machine or controls. The machine shall be equipped with a slow speed wheelhead spindle drive system capable of performing automatic and manual multiform wheel crush dressing of any form as may be desired.

3.2.1 The machine shall consist essentially of and not be limited to the following: a base, platen, wheel head, work head, tailstock, lubrication system, feed mechanism, electrical drive motor(s) and controls, coolant filtration system, coolant heat exchanger, mist collector, high pressure (10,000 psi) wheel cleaner, wheel crusher dresser,center work support and pedestal work support systems.

3.2.1.1 Base: The base shall be a heavy box type casting of close grained cast iron or semi steel, rigidly constructed to provide maximum support to the platen so that the platen will perform at maximum efficiency under full load. All corners shall be neatly rounded, free of sharp edges and projections for safe operation. The base shall be well proportioned and adequately ribbed and braced at frequent intervals to provide maximum rigidity

and strength, to maintain original alignment and resist deflection, distortions and undesirable vibrations under continuous maximum load.

The base shall be provided with leveling pads, wedges, or, leveling screws of the hollow jack screw type to permit jacking and hold-down on the same common axis. The leveling screws, wedges or pads shall be provided in sufficient quantity, strategically located and easily accessible to facilitate installation and to assure and maintain original alignment and leveling of the base and the units mounted thereon under continuous maximum load. When applicable, access door(s) or removable plate(s) shall be provided in the base for convenience in servicing components housed within the base. The machine and related components or equipment and all associated peripheral support mechanisms shall require no excavation for installation.

3.2.1.2 Platen or Worktable: Shall be of the air bearing design and of the same structural material as the base, machined to a high degree of accuracy. The worktable or platen shall carry the headstock, center work support and tailstock. The platen shall be well ribbed for adequate strength, securely clamped to the top of the machine base. The platen shall be well angled to direct grinding forces into the base of the machine. Precision ways shall be provided for locating and locking the workhead (headstock) and tailstock and to guide, support and align the workpiece. The platen table shall be of sufficient length to fully support any workload within the capacity of the machine and be so designed to be free from any warpage and have minimum wear over a long period of use. The ways shall be protected from grit and foreign matter. The platen table shall be elevated by plant air (65 psi) minimum, for ease in traversing by handwheel. Means shall be provided for automatic locking to prevent longitudinal table movement while plunge grinding. The worktable shall be equipped with a direct reading optical scale mounted at the front of the machine with capabilities for positioning the table to the nearest .0001". The optical device shall be well lighted for ease in reading. The platen shall

be equipped with a means of conveying coolant back to the coolant sump or reservoir as it flows from the work area. This system shall be equipped with sufficient ports so that no coolant is allowed to overflow and fall to the floor or surrounding areas.

The top surface of the platen table shall be machined true, flat, and parallel to its bearing surfaces and the horizontal axis of the spindle within .001" of its full length and width.

The table top surface shall be provided with accurately machined tee-slots running longitudinally and parallel with the bearing surfaces the full length of the table, conforming dimensionally with USAS B5.1. Cross slots shall be provided and be precision machined for guide and set-up purposes.

3.2.1.3 Wheelhead: Shall be a rigid one-piece casting of close grained cast iron or semi-steel, designed to house and rigidly support the spindle, spindle drive and feed mechanism.

The assembly shall be equipped with compatible precision machined and finished bearing surfaces to receive the base ways and to accurately guide and align the spindle with the machine table. Precision indicating surfaces parallel to the axis of the spindle shall be provided for aligning the assembly on the way section. Means shall be provided to maintain parallelism of the spindle travel within .0002" along a 12" length.

Adjustable and fixed safety dogs or limit switches shall be provided to safely limit the extent of wheel head travel and prevent damage to any part of the system.

A means shall be provided for manually traversing the wheel head unit, its full length for set-up purposes. The wheelhead motor shall be statically and dynamically balanced within .0002", and equipped with mountings which will prevent vibration or undue tension on the wheel spindle. The spindle shall be made from the best grade alloy of steel obtainable, heat treated, precision ground and running in anti-friction bearings, automatically lubricated with oil mist. The spindle shall be cool running and sealed to prevent any moisture, grinding grit or foreign material from entering the bearings. The wheelhead spindle shall be of the dead shaft design, supported at both ends by tapered roller bearings to absorb the forces associated with heavy duty abrasive machining. The spindle shall be equipped with an ammeter and tachometer to visually show spindle load and speed, easily visible to the operator from normal operating position.

3.2.1.4 Workhead: The workhead shall be a rigid one piece casting of closed grained cast iron or semi-steel, designed to house the live center drive system. The work head shall be capable of supporting and driving any load within the range and capacity of the machine. The workhead shall have a compatible mating bearing surface for mounting and aligning with the platen. A means shall be provided to clamp and secure the workhead in any desired position along the platen. The live center workhead shall be driven by a precision balanced DC motor which shall provide infinitely variable work speeds within the range and capacities of the machine. DC rectifying equipment shall be provided for conversion to AC. The spindle shall be made from the

best grade of forged alloy steel, heat treated, precision ground and mounted on anti-friction bearings. An adequate method of providing lubrication to the workhead shall be provided.

3.2.1.5 Tailstock: The tailstock shall be a rigid one piece casting of close grained cast iron or semi-steel designed to house the tail stock quill. The tailstock shall be of the air bearing design for ease in positioning, capable of supporting the loads within the range and capacities of the machine. The tailstock shall have compatible mating bearing surfaces for mounting and aligning with the platen. A means shall be provided to manually and automatically clamp and secure the tailstock in any desired position along the platen. The tailstock assembly shall have an air or hydraulically operated quill with adequate pressure regulators and controls to provide correct pressure thrust loads between the work piece and centers.

3.2.1.6 Lubrication System: The machine shall be provided with a completely filtered automatic pressure lubrication system for all moving parts where practical, with sight inspection gages provided where necessary to determine the oil level, and, manual lubrication fittings provided for all running parts requiring lubrication where automatic lubrication is impractical. Audible or visual signaling devices shall be provided to indicate power lubrication malfunction. Concentration for warning or audible signal devices shall be on the wheel head spray mist system and all internal pressure lubricated systems.

Automatic lubrication shall not require manual connection or disconnection between various moving components of the machine.

A lubrication oil pressure gage or signal light shall be provided and installed in this system and shall be easily visible to the operator.

3.2.1.7 Feed Mechanism: The machine shall be equipped with an automatic hydraulic wheel in feed system. This system shall have provisions for manual operation of the feed as desired. The system shall have a positive stop to determine precise location. The hand wheel shall be calibrated in .0005" or less for fine in feed as desired. The infeed shall be variable over the full range of .005" to .475 inches per minute controllable by means of a heavy duty calibrated potentiometer. An automatic feed reversing system shall be provided to permit the wheel to retract into a crush dressing roll to recondition the grinding wheel as often as may be desired. The hydraulic system for the feed mechanism shall be complete, all pumps, valves, cooler (if required), cylinders, and pressure controls shall be furnished mounted and connected. Overload protection shall be provided on the high pressure line from the hydraulic pump to prevent damage to the hydraulic fluid supply. This system shall be filtered to assure clean fluids to the hydraulic circuit. A sight gage shall be fitted to the hydraulic reservoir to indicate fluid level. The hydraulic system shall be provided with a suitable air cooled heat exchanger, if required, to maintain hydraulic oil temperatures at a range for uniform response characteristics of the machine. Water cooled is not acceptable.

3.2.1.8 Center Work Support: The machine shall be equipped with a suitable adjustable roller type air bearing table work support system, capable of supporting rotating work or gun tubes within the length and weight capacities specified in paragraph 1.1.2. This system shall be capable of being moved along and secured to the table so that rotating gun tubes can be supported or accommodated in various positions along the table or platen as desired.

3.2.1.9 Pedestal Work Support: The machine shall be equipped with a suitable adjustable pedestal roller type gun tube centering and supporting system connected to and forming part of the base of the primary machine. The pedestal work support and centering system shall be of rugged design and manufactured with adequate strength and rigidity to properly support and retain gun tubes within the length and weight capacities specified in paragraph 1.1.2. This system shall be designed and constructed in such a manner so that sufficient end thrust loads can be applied to retain the rotating gun tube or work on center in proper alignment in and against the work head or work head center. This system shall be hydraulically operated, and fully equipped with all necessary controls, gages, hoses, valves, pumps, cylinders, motors and reservoirs for the most severe grinding operation intended.

3.2.1.10 Electrical equipment shall include motors, controls, switches and starters. All electrical units shall be completely wired including transformers of adequate current and voltage ratings to accommodate all control circuits and auxiliary panel feed source requirements. Power source available is 3 phase, 60 cycles, 460, 230 or 115 volts AC ± 3%, all electrical units shall be rated for this voltage and tolerance.

The wheel drive motor, the work drive motor and the wheel crushing speed motor shall be of horsepower specified under range and capacity paragraph 3.3.3 of this specification.

All electric motors shall be dynamically balanced and equipped with permanently lubricated and sealed bearings. Overload relays shall be provided where applicable. All motors shall be clearly marked with an arrow to indicate direction of rotation.

One (1) each, master control lock-out switch shall be provided and arranged for positive locking in the "OFF" position when the machine is not in use.

Horsepower or load meters for the drive units, easily readable with large calibrated dials to indicate horsepower being used in conjunction with wheel and work drive motors, shall be provided.

The machine shall be equipped with overload protection which will automatically shut down the machine in the event the wheel stalls due to overload.

Controlled artificial light facilities and equipment capable of handling up to 250 watts each shall be furnished for all hooded or concealed work areas.

The machine tool shall be completely wired to power source hook-up. All motors, controls and wiring shall be oil, water and dust-proof. If DC power is required for any operation, necessary rectifying equipment shall be provided.

All manual controls shall be operable on a reduced voltage of 110V or 24V and mounted in a control panel conveniently located to the operator.

3.2.1.11 Coolant and Coolant Filtration System: A complete coolant and coolant filtration system shall be furnished. This system shall be Delpark Filtermatic #8-9 x 36 or equal capable of filtering 10 microns or less. The system shall include reservoir, oil resistant hoses, strainer, pump with necessary tubing, operating control valve, and a universal delivery to the work piece. The reservoir shall be equipped with screen and drain plug. The coolant delivery system shall permit the operator to direct and control the amount of coolant flowing on the work. The coolant system shall not require excavation. Coolant system shall have a coolant capacity adequate for full coolant supply at maximum pressure and gallons per minute. Coolant used will be Metgrind WV-2 or equal. The reservoir shall have adequate capacity to sustain full coolant supply at maximum pressure and volume.

3.2.1.12 Coolant Heat Exchanger: The coolant system shall be equipped with an air cooled automatic mechanical refrigeration system. The refrigeration system shall be capable of handling the maximum capacity of the coolant tank and maintaining temperatures of coolant at operating temperature under continuous operation of the machine.

All components of the coolant system shall be easily accessible for maintenance and cleaning.

The refrigeration system shall be controlled by electrical circuit independent of the main control circuit, in order that the refrigeration system may be operated when the machine is completely shut down. This system shall be capable of maintaining adequate temperature control of the grinding fluid within $\pm$ 5° of preset requirements. This system shall be a minimum of 15 H.P. Hansen or equal, capable of cooling a minimum of 150,000 BTU/hr. This system shall be refrigeration air cooled (water cooled is not acceptable). This system shall be complete in its entirety.

All electrics, air piping, plumbing, pumps, fans, switches, relays, overload protection, motor starters, control panels, push buttons etc. shall be fully assembled and connected to the main coolant system of the machine.

3.2.1.13 Mist Collector: A mist collector, electrostatic precipitator type capable of removing the maximum amount of mist or coolant fog resulting from the most severe grinding operation shall be provided. This system shall be a Smog Hog or equal, capable of removing and processing a minimum of 2400 cubic feet of dirty coolant saturated air per minute. This air mixture will contain an assortment of grinding debris, coolant and shop air. This mixture shall be drawn through filters ionized by a high voltage charge. Particles of coolant shall be collected in the proper area, cleaned and returned to the grinding

operation. All air after cleaning shall be silently exhausted into the surrounding area. This system shall be complete having all electrics, air, piping, plumbing, pumps, fans, switches, relays, overload protection, motor starters, control panels, push buttons and all duct work, flexible or rigid, fully assembled and connected to the grinding machine.

3.2.1.14 Wheel Cleaner: An automatic jet wheel cleaner system shall be provided and mounted so that when actuated it shall direct a series of high pressure (10,000 psi) streams of coolant against the wheel face and wheel edges, oscillating across the wheel face during grinding or crushing, removing all metal swarf before it becomes embedded in the grinding wheel. This system shall be complete, mounted on the machine connected with all rigid and flexible high pressure lines and all items necessary for operation as intended.

3.2.1.15 Crusher Dresser: An automatic compensating hydraulic attachment shall be provided for crush dressing grinding wheels suited for this machine. This system shall be self contained, securely bolted and housed to the base of the machine and located to the rear of the grinding wheel. An anti-friction type arbor, at least 3" in diameter, shall be provided on to which the crush roll will be mounted. The crush feed system shall provide infinitely variable infeed rates from .004" to .500" per minute. The crush dressing cycle shall be automatic and shall be controlled by an electrical switch on the machine control panel. Closing of this switch shall start coolant flow, start rotation

of grinding wheel at slow crushing speed and feed the grinding wheel into the crush roll at a uniform but controlled speed and feed. This cycle shall continue until the preset or desired amount of dressing is reached.

3.2.1.16 Splash Trays: Shall be provided to confine, contain and route swarf to a suitable and convenient area for disposal. This system shall be designed and manufactured so that no coolant or swarf is allowed to fall to the floor or surrounding area.

3.3 Range & Capacities: Requirements are not less than shown, where range and capacities are shown, the required performance is from the stated minimum to the stated maximum.

3.3.1 Work Capacity: Ref. Paragraph 1.1.2 (In part)

| | |
|---|---|
| Maximum work length | 260" |
| Maximum work diameter | 13" |
| Minimum work diameter | 7" |
| Minimum work length | 90" |
| Maximum work swing diameter | 19" |
| Maximum work form depth | 2" |
| Maximum work form width | 12" |
| Maximum work weight | 6000 lbs. |

3.3.2 Grinding Wheel:

| | |
|---|---|
| Maximum diameter | 42" |
| Minimum diameter | 36" |
| Minimum width | 12" |
| Hole diameter | 20" |

3.3.3 Machine

| | |
|---|---|
| Wheel Speeds | 635 RPM |
| Work speeds | 16 to 38 RPM |
| Wheel Head Adjustment | 18" |
| Wheel Head Rapid Travel | 3" |
| Wheel Head Automatic Feed | 2" |
| Wheel Infeed Rate | .004" per minute to .060" per minute. |
| Crush Feed Range | .002" to .012" per minute |
| Coolant Pump Capacity | 150 gallons per minute @ 150 lbs per sq. in. |
| Coolant Filtering Unit Capacity | 150 gallons per minute |
| Coolant Refrigeration Unit Capacity | 150 gallons per minute |

3.3.4 Electrical:

| | |
|---|---|
| Wheelhead motor (Prec. bal). | 150 HP |
| Workhead motor (Prec. bal) | 25 HP |
| Slow wheel crush speed motor | 7-1/2 HP |
| Coolant pump motor | 25 HP |
| Rapid traverse pump motor | 3 HP |
| Slow feed pump motor (statatrol) | 1/2 HP |
| Coolant Heat Exchanger Motor | 15 HP |

3.4 Additional Equipment: The following equipment shall be furnished with each machine: One (1) set of hand tools normally furnished by the manufacturer.

3.5 Nameplate: A corrosion-resistant metal nameplate, permanently and legibly marked with the following information in accordance with MIL-STD-130 shall be securely attached to each machine. If the machine is a

special model, the model designation shall include the model of the basic standard machine and a suffix keyed to the manufacturer's permanent records. The captions listed may be shortened or abbreviated provided the entry for each such caption is clear as to its identity.

Nomenclature

Manufacturer's name

Manufacturer's serial number

Size ____________________

Table working surface - width _____ inches, length _____ inches.

Manufacturer's model designation

Power input characteristics and rating

Contract number

Federal Stock number or Plant Equipment Code

Date of manufacture

U.S. #________________________________

4. Quality Assurance Provisions:

4.1 Responsibility for inspection: The supplier is responsible for performance of all these tests and inspections specified herein. The supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification when such action is deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Quality conformance inspection: Each item shall be subjected to quality conformance inspection prior to being offered for acceptance. The requirements of quality conformance inspection shall comprise the examination in 4.4, the tests in 4.5.1. Failure of the item to pass any examination or test shall be cause for total equipment rejection.

4.3 Alignment Accuracy Test

| Test to be applied | Allowable Deviation |
|---|---|
| Platen or worktable flat or level in longitudinal direction | 0.0002/12" |
| Platen or worktable flat or level in transverse direction (no twist permitted) | 0.0002/12" |
| Wheelhead flat or level in work direction (no twist permitted) | 0.0002/12" |
| T-slots parallel with worktable movement | 0.002/12" |

4.4 Examination: The machine and equipment shall be examined to determine compliance with this specification.

4.5 Tests:

4.5.1 Methods of furnishing test data

The alignment tests required in 4.3 shall be made by the manufacturer who shall furnish the designated Government representative with a certified copy of the results thereof. The remaining tests specified in 4.5 shall be made and test information shall be made available to the Government.

The manufacturer shall complete designated tests specified in 4.2 through 4.5.3 and after completion of these tests shall notify the procuring agency of their completion. If the machine meets requirements of tests specified, all tests in 4.2 through 4.5.3 shall be repeated

with Watervliet Arsenal representatives present to witness all tests. These tests will be repeated at Watervliet Arsenal, and, the final acceptance will be made at this Arsenal.

4.5.2 Operational Test: The machine shall be operated under manual and automatic control with spindle turning at no load for not less than 40 hours for an initial warm-up period. During this period, proper operation of all automatic controls, manual controls, motors, adjustment mechanisms, dials, gages and accessories shall be verified. This operational test is intended to check operability only. No grinding tests are part of the operational test. A check of accuracy is required by the operational test. A record of spindle temperature, wheelhead repeatability, and all automatic cycle operations shall be recorded and made available to Watervliet Arsenal representatives.

4.5.3 Performance Test: Performance test shall be conducted at the contractor's plant. Performance test shall comply with all requirements of paragraph 1.1.6 of this specification. These tests will constitute preliminary requirements for final acceptance of the machine from the contractor. All tests shall be witnessed by representatives of Watervliet Arsenal. Final Acceptance of the machine and equipment shall be made after installation, assembly and testing at Watervliet Arsenal. Testing at Watervliet Arsenal will be complete after the successful machining of each component specified in paragraph 1.1.6, representing a total of three (3) each 105mm M68 gun tubes and three (3) each 155mm M185 gun tubes. All tubes shall be machined in accordance with routing and drawing specifications cited. Each tube machined shall not exceed the floor to floor time specified in paragraph 1.1.6 under mandatory maximum floor to floor time allowed per gun tube.

5. Literature Requirements

5.1 Bidder shall submit in triplicate, brochures, cuts, illustrations, drawings and narrative description which clearly indicates that the design, construction and operating features of the machine and all related equipment offered will meet each of the requirements as set forth in this specification. The literature shall indicate the overall size and configuration of the machine and all related component parts, and must assure that the range and capacities will be met by the machine and equipment being offered. This data is required for evaluation of equipment offered for conformance with this specification. Bids or any offer submitted without the data specified in paragraph 5.1 will be rejected.

5.2 Literature covering more than one model or size must be clearly and independently marked to indicate the exact model and size being proposed or offered.

5.3 The contractor shall supply floor layout templates measuring 1/8" per foot to cover all equipment furnished.

6. Technical Reports: The contractor shall furnish complete technical reports in triplicate of all technical engineering and cost data generated as a result of this procurement. The reports shall contain charts, speeds, feeds, wheel materials, wheel cost, crush roll material, crush roll cost, coolants, time values, production rates by lots of 10 and lots of 100, floor to floor time per tube machined, cost savings, economic analyses, cubic volume of metal removed, surface finish, dimensions and number of times to crush dress wheels per component ground. The above information shall be submitted on each component specified in paragraph 1.1.6 of this specification.

7. Preparation for Delivery:

7.1 Preservation and packaging shall be in accordance with the latest revision to Military Specification MIL-M-18058, at level C.

7.2 Packing shall be in accordance with the latest revision to Military Specification MIL-M-18058, at level C.

7.3 Marking shall comply with Military Specification MIL-STD-129.

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